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Research Article (Subject – Sedimentology)

Lithofacies and Process Sedimentology of the Dad Sandstone Member of the Lewis Shale Formation, South-central Wyoming, U.S.A.

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Abstract

The Dad Sandstone Member of the Lewis Shale Formation shows a distribution of facies that suggests the sandstones filled sinuous leveed-channel deposits. The shale-clast conglomerates are thought to be the product of slumping of adjacent levee walls from the steeper channel margin, and the cross bedded sandstones are interpreted to be in-channel bar or dune forms. These channels probably fed sand into the deeper basin contemporaneously with levee formation; the channel-fill sandstones represent the product of later backfilling episodes. The slumped and erosive nature of some channel margins supports this overall interpretation.

Keywords: Depositional process sedimentology, Lewis Shale, Deepwater, Channel-levee, Hydrodynamic interpretation, America.

Introduction

Depositional process sedimentology, a subdiscipline of physical sedimentology, is concerned with the detailed bed-by-bed description of siliciclastic sedimentary rocks for establishing the link between the deposit and the physics and hydrodynamics of the depositional process (Shanmugam, 2006). It is the foundation for reconstructing ancient depositional environments and for understanding sandstone reservoir potential. Interpretation of depositional processes from the rock record is possible because physical features preserved in a deposit directly represent the physics of sediment movement that existed at the final moments of deposition (Middleton and Hampton, 1973).

The deepwater Dad Sandstone Member, Lewis Shale, of Wyoming, consists of nine aggradationally stacked channel-fill sandstones that comprise a 255 ft. thick stratigraphic succession. Original work performed by Witton (2000) and Slatt (2000, 2001a, 2001b and 2002) interpret Spine 1 to comprise of a sinuous leveed-channel system. Their interpretation proposes that the steeper side of each channel-fill sandstone is interpreted to have abundant number of debris flow deposits (represented by facies F7, shale-clast conglomerate facies) and the shallower side was interpreted to contain a cross-bedded

sandstone facies (represented by facies F3, cross-bedded sandstone) (Witton, 2000 and Van Dyke, 2003).

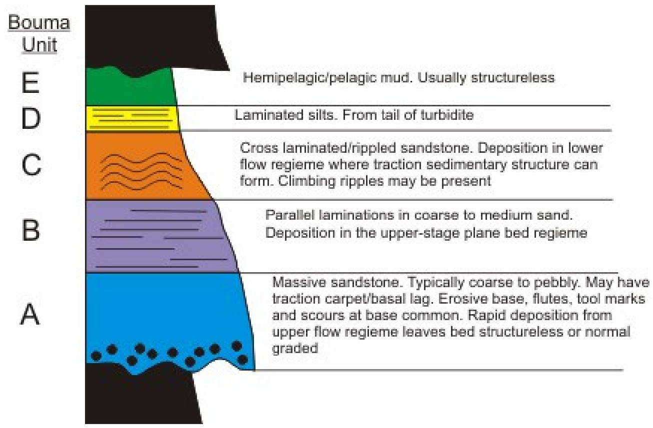

Fig. 1. Classic Bouma Sequence deposits (Tiwari, 2012).

Each channel-fill sandstone is separated by thin-bedded, very fine sandstone/mudstone strata. Channel facies include structureless sandstone with fluid escape structures, structureless sandstone without fluid escape structures, rippled to climbing rippled sandstone, parallel to subparallel laminated sandstone, cross-bedded sandstone, shale-clast conglomerate, thin-bedded sandstone/mudstone, and slumped beds. In separate channel-fill sandstone, these facies can be complexly interbedded, but there is a tendency for shale-clast conglomerates to comprise the base and one side of a channel-fill, whereas cross-bedded sandstones comprise the opposite side. Massive/fluid escape structured sandstones typically occupy the top of these successions. Proximal to distal levee beds occur adjacent to some of the channel sandstones.

The objective of this article is to document the Dad Sandstone Member's physical properties of lithological successions affiliated to the Dad Sandstone Member. The accompanying hydrodynamic conditions are then interpreted for each lithofacies deposited and described in the text below.

Methodology

The deepwater Dad Sandstone Member, Lewis Shale, of Wyoming, consists of nine aggradationally stacked channel-fill sandstones that comprise a 255 ft. thick stratigraphic succession. This succession has been documented by measuring 121 closely-spaced outcrop stratigraphic sections, decimeter-scale GPS-tracing (Global Positioning System) of bed boundaries, drilling and gamma-logging of 8 shallow boreholes, ground-penetrating radar (GPR), and electro-magnetic induction (EMI) behind the outcrops. However, many methodological part results will be published elsewhere.

Results and Discussion

Eight lithofacies are recognized in the field; they are: F1) sandstone with water-escape structures [some cross-bedded], F2) structureless sandstone [without water-escape structures], F3) cross-bedded sandstones [without water-escape structures], F4) parallel to subparallel laminated sandstone, F5) rippled or climbing rippled sandstone, F6) shale or mudstone, F7) shale clast conglomerates, and F8) slumped beds. With the exception of the shale-clast conglomerates (F7) and slump beds (F8), the facies are fine-grained and well-sorted.

Three of the eight facies constitute classic Bouma Sequence deposits (Fig. 1); they are: F4, F5, and F6. F4, parallel to subparallel laminae is categorized as Bouma division Tb. Rippled or climbing-rippled sandstone, F5, is interpreted as Bouma division Tc and is the product of traction of grains along the sea bed during lower flow regime conditions (Weimer and Slatt, 2006). The final facies categorized within

the Bouma Sequence is F6, a shale or mudstone, denoted by Te.

Lithofacies 1 (F1): Structureless to Cross-Bedded Sandstone with Water-Escape Structures

Description

The structureless to cross-bedded sandstone with water-escape structures consists of yellowish-tan, fine-grained, well-sorted sandstone. It is the second most abundant facies. This facies exhibits primary low-angle cross-bedding in some exposures, and in all of the exposures, secondary water-escape "knobs" (Fig. 2). Water escape structures are common in the upper portions of the outcrop exposures, particularly in Channel-fill Sandstone 1 (Fig. 2 and 3). This position within the channel-fill facies sequence indicates that these sands may have been deposited as liquefied/fluidized flows.

Fig. 2. "Knobby" texture interpreted as weathered vertical/subvertical dewatering pipes.

Interpretation

Sandstones with water-escape structures, such as vertical pipes, are formed by hindered settling of sediments in a liquefied and/or fluidized flow (Weimer and Slatt, 2006). As the sediment in this facies is finally deposited, water migrates toward the top of the flow, leaving a cavity in its pathway into which the surrounding sediments collapse (Fig. 6). Because grain size varies within the deposit, differential cementation occurs, giving rise to surficial differential weathering and the development of the more resistant "knobs" (Slatt, personal communication, 2003).

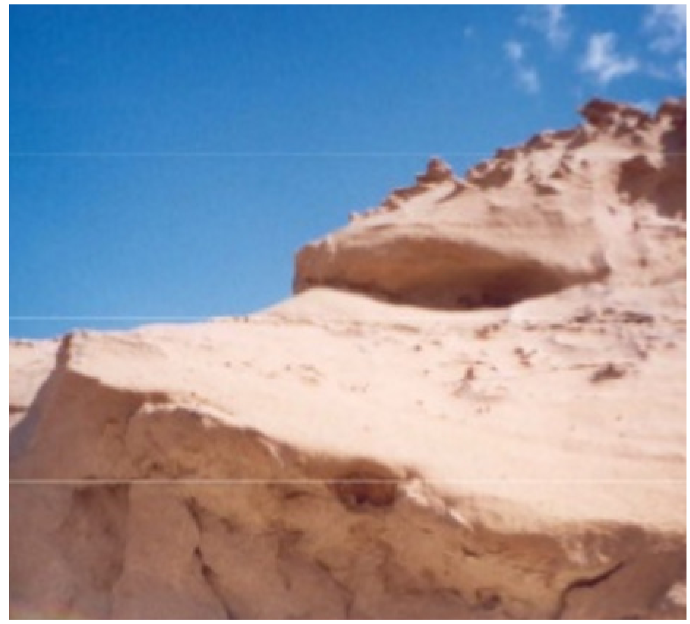

Fig. 3. Dewatering pipes located at the top of Channel Sandstone 1.

Lithofacies 2 (F2): Structureless Sandstones without Water-Escape Structures

Description

Structureless sandstone without water-escape structures are the most abundant facies within the outcrops (Fig. 4). It is a yellowish-tan sandstone. This sandstone does not exhibit any visible primary or secondary sedimentary structures. Thickness of this facies can reach significant heights (up to 80% of the channel-fill stratigraphic column, in some cases up to 24ft) and may represent many separate flow events.

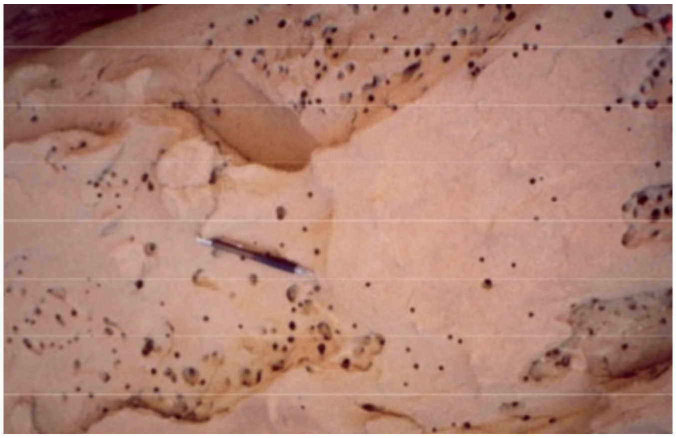

Fig. 4. Structureless Sandstone with geologically unrelated holes pockmocking surface of Channel-fill Sandstone 3.

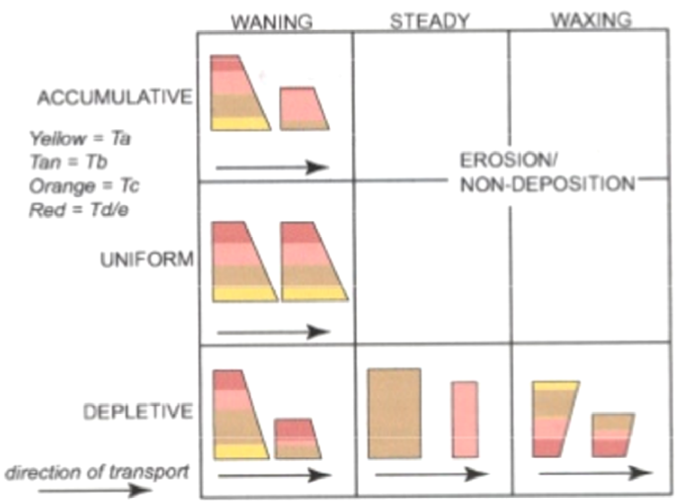

Fig. 5. Temporal and Spatial relations in flow environments (Modified from Kneller, 1995).

Interpretation

Structureless sandstones are deposited in only one spatial and temporal flow condition, steady depletive (Kneller, 1995; Fig. 5). Both Walker (Fig. 6; 1978) and Lowe (Fig. 7; 1982) differentiated structureless sandstone from Bouma division Ta. This was based on the interpretation that these sandstones tended to exhibit: 1) water-escape structures, 2) fewer associated shale interbeds, 3) an increase in erosionally-based and irregularly bedded sandstone, and 4) sandstone beds that are thicker than associated beds (Weimer and Slatt, 2006).

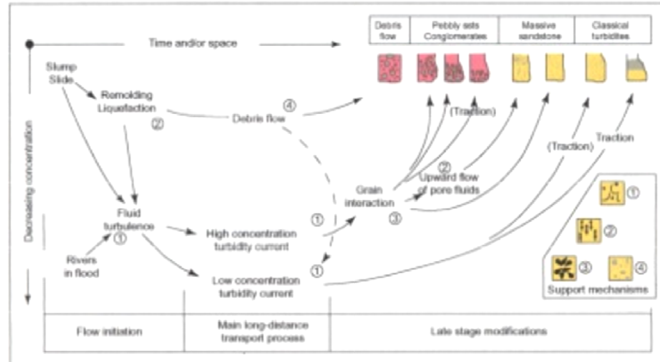

Fig. 6. Walker's (1978) classification of deepwater deposits.

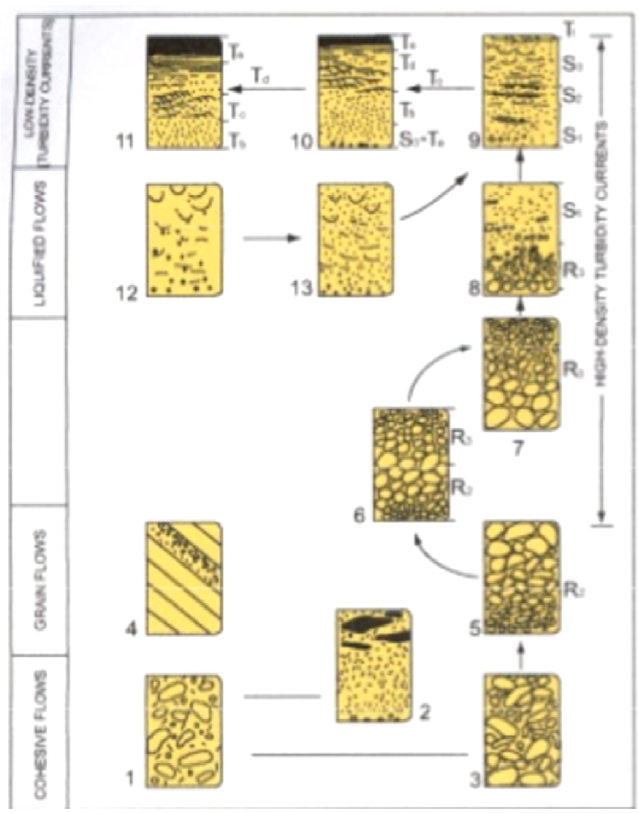

Fig. 7. Lowe (1982) classification of High Density Turbidity Current (HDTC) and Low Density Turbidity Current (LDTC).

Lithofacies 3 (F3): Cross-Bedded Sandstones without Water-Escape Structures

Description

This yellowish-tan sandstone is the third most abundant facies. These deposits tend to manifest

low-angle, high amplitude cross-bedding features (Fig. 8). Many times it is difficult to reveal the low-angle cross-bedding in the field because of the position of the sun.

Fig. 8. Low-angle, high amplitude crossbedding from Channel 1 (Source: Roger Slatt, 2002).

Interpretation

Primary cross-bedding is formed by sediments that move along the seafloor as tractive bedload. Traction can be defined as "a mode of sediment transport in which the particles are swept along (on, near, or immediately above) and parallel to a bottom surface by rolling, sliding, dragging, pushing, or saltation" (Jackson, 1997). Crossbedding is a lower flow regime feature. The low-angle nature of the cross-bedding indicates that these features were most likely in-channel bar or dune forms (Slatt, personal communication, 2003). The in-channel barforms are interpreted to lie on the point bar-equivalent side of the channel-fill system or upon the channel floor.

Lithofacies 4 (F4): Parallel to Subparallel Laminae.

Description

Parallel to subparallel laminae, L4, are found in yellowish-tan, fine-grained, well-sorted sandstone (Fig. 9 and 10). The deposit was not found in abundance in the field. This facies is characterized by parallel to subparallel bedding planes, or laminations. It occurs within many of the stratigraphically higher channel-fill sandstone bodies, i.e., Channels 6 – 10.

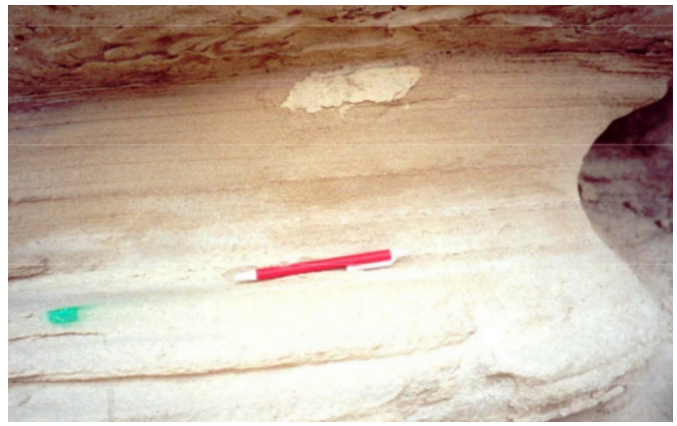

Fig. 9. Planar laminae on outcrop exposure on Channel-fill Sandstone 6.

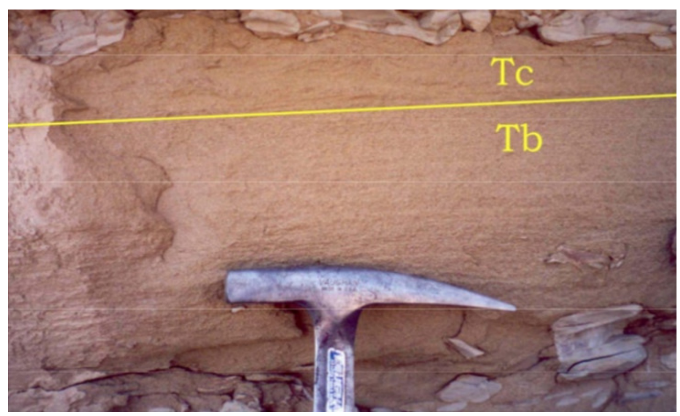

Fig. 10. Planar laminae located in Channel-fill Sandstone 1.

Interpretation

Planar bedding occurs in both the lower and upper flow regime. It exhibits parallel bedding. For lower flow regime deposits, the flow velocity is very low. This is a very simple deposit, exhibiting only planar bedding in plan view and horizontal laminae in side view.

Planar bedding, deposited in upper flow regime conditions, exhibits current lineations due to the high flow velocity. Current lineations form as concentrations of heavy minerals align themselves in the direction of flow. In plan view, the current lineations are visible, but only the laminae can be seen from the side view.

Figure 10 exhibits Bouma division Tb-Tc, categorizing Tb within the lower flow regime; all F4 deposits in the field are interpreted to be lower flow regime planar bedding.

Lithofacies 5 (F5): Rippled or Climbing-Ripple Sandstone

Description

Facies F5, exhibits ripples or climbing-ripples in a yellowish-tan sandstone. This deposit is not abundant within the outcrop exposures, however, nearly all nine channel-fill sandstone bodies contain this facies. Channel-fill Sandstone 6 contains a 2’2” thick set of climbing-ripples (Fig. 11). The climbing-rippled sandstone includes those with lee slope deposition, as well as those with lee and stoss slope deposition (Fig. 12).

Fig. 11. Climbing-Ripple Facies located in Channel-fill Sandstone 6.

Interpretation

Rippled sandstone and climbing-rippled sandstone are categorized in the uppermost division of lower flow regime deposits. Standard ripples are formed by particles as they move by traction along the seafloor. Slowly they stack upon one another until the angle of repose is met (28º - 30º), and at this point the sedimentary particle is transported along the face of the lee slope, where either it remains or continues to move. The climbing-rippled sandstone has a sedimentary input that exceeds its sedimentary output, particularly those with lee and stoss slope deposition. These deposits are diagnostic of a sediment-choked system and are interpreted to occur at either the inner channel-levee margin of the channel-fill environment or in proximal levee environments (Browne and Slatt, 2002).

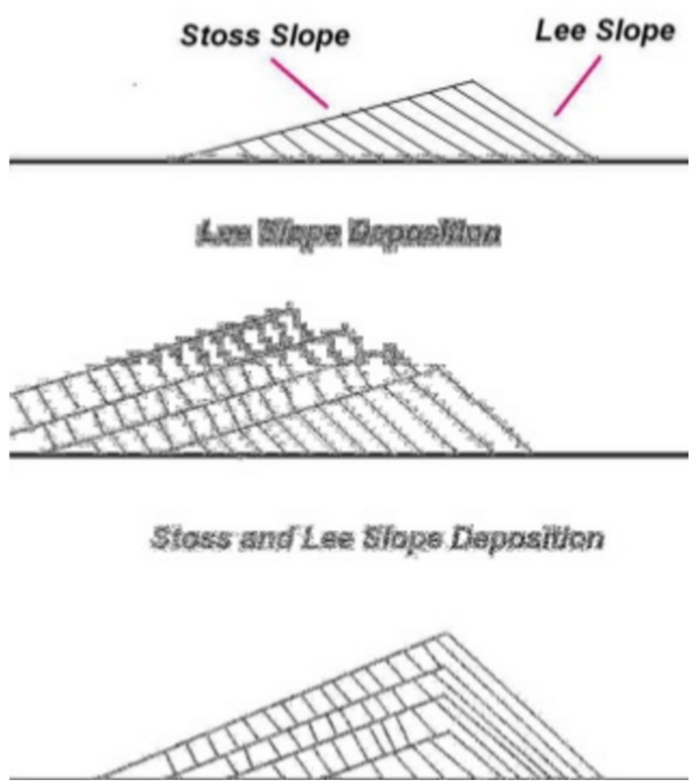

Fig. 12. Climbing-ripple facies description.

Lithofacies 6 (F6): Shale or Mudstone

Description

The shale and/or mudstone located within the channel-fill sandstones tend to exhibit erosive tops (Fig. 13). This facies is colored light to dark gray and is composed of clay-sized particles. F6 is mostly absent from many of the channel-fill sandstone bodies, but is quite abundant within Channel-fill Sandstone 1.

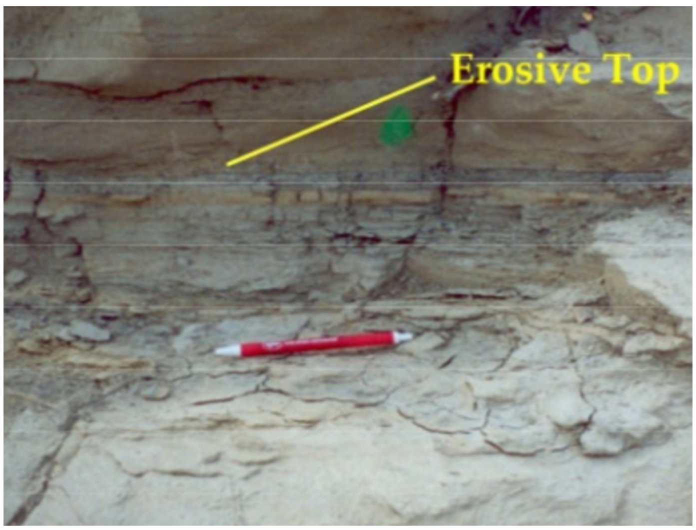

Fig. 13. Shale/mudstone facies bounded by structureless sandstone facies.

Interpretation

Facies F6, shale and/or mudstone, is interpreted to be deposited from either the tail-end of a turbidity current flow or as pelagic rain. The major process by which this facies is deposited in the channel-fill environment is interpreted to be the tail-end of a turbidity current flow. Channel-fill lithologies are comprised mainly of sandstone facies. Since very few F6 facies are exhibited in the field, it is interpreted that any shale and/or mudstone located in the channel-fill environment must be deposited as the tail-end of a turbidity current as opposed to pelagic rain (not quiescent enough in this environment for this type of deposition to occur).

Lithofacies 7 (F7): Shale-Clast Conglomerates

Description

The shale-clast conglomerates of the channel-fill sandstones in Spine 1, F7 (Fig. 14 and 15), are light to dark gray in color. The shale clasts are light gray and the matrix is dark gray or yellowish-tan. The internal architecture exhibited within the shale clasts themselves show a thinly laminated facies. Additionally, the shale clasts exhibit imbrication within this faices. L7 is quite abundant and is located in almost all of the channel-fill sandstones. F7 tends to occur mainly as small, thin deposits (usually 2-4in thick).

Fig. 14. Stacked shale-clast conglomerates (A) interbedded with turbidites (B) on Channel-fill Sandstone 1.

Fig. 15. Faint imbrication of shale clasts occur in Channel-fill Sandstone 1.

Interpretation

The shale-clast conglomerates are interpreted to have originated as debris flow deposits. These flows contain a high matrix strength and therefore move in a plastic, laminar, cohesive state (Weimer and Slatt, 2006). As the debris flow is transported, the flow region is delineated into two components, the Shear Flow Region and the Plug Flow Region (Fig. 16). The Shear Flow Region, located at the basal part of the flow, generates shear stresses that overcome the matrix shear within the flow (Weimer and Slatt, 2006). It is possible that shale clasts found in the lower regions of debris flows (i.e., in the Shear Flow Region) could have been imbricated by these shear stresses (Fig 15). The Plug Flow Region contains the major bulk-volume of sediments in transport. It tends to remain in the same position during its entire transit, except at the flow/seawater contact where the sediments may exhibit a decrease in velocity due to frictional forces (Weimer and Slatt, 2006). In Spine 1 deposits, shale clast conglomerates are interpreted to comprise the failed, slumped margins of levees.

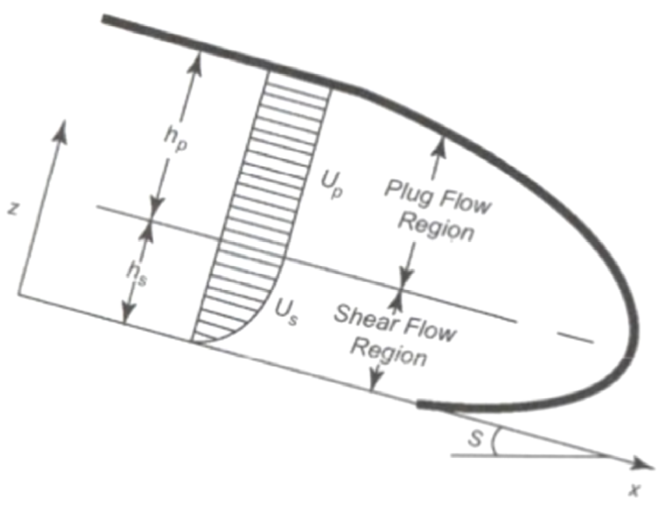

Fig. 16. Debris Flow Rheology (from Weimer and Slatt, 2006).

Lithofacies 8 (F8): Slump Beds

Description

Slump beds (Fig. 17) are found only in a few of the channel-fill sandstones, but are a very diagnostic feature, helping to orient the channel-fill sandstone into its environment within the channel system. They tend to range in thickness from 2ft to 7ft. F8 exhibits many different characteristics within their deposits, including the parallel interbedding of sandstone and siltstone and a lower sand/shale ratio than other lithofacies. They range in color from yellowish-tan to light and dark grey.

Fig. 17. Slump beds bounded in yellow from Channel-fill Sandstone 1 "Prong."

Interpretation

Slump beds are interpreted to have formed as a coherent unit of the failed inner-channel margin wall within a leveed-channel system. They represent the initial flow event of any sedimentary gravity flow and exhibit high matrix strength. Due to their high sediment concentration they move in a plastic flow state (Weimer and Slatt, 2006). This facies is closely related to the hydrodynamic interpretation of F7, but it differs from it mainly by the fact that the deposit exhibits a coherent unit of different beds while F7 is one bed. The interpreted slump beds contain what was once the channel margin, comprised largely of proximal-levee facies deposits. All of this evidence points to slump beds having been formed on the steep side of the channel margin, or the cutbank-equivalent side of a channel-fill system.

Conclusions

This research study yielded many new insights into the depositional facies and patterns of the Dad Sandstone Member of the Lewis Shale. Eight lithofacies are recognized in the field; they are: F1) sandstone with water-escape structures [some cross-bedded], F2) structureless sandstone [without water-escape structures], F3) cross-bedded sandstones [without water-escape structures], F4) parallel to subparallel laminated sandstone, F5) rippled or climbing rippled sandstone, F6) shale or mudstone, F7) shale clast conglomerates, and F8) slumped beds. With the exception of the shale-clast conglomerates (F7) and slump beds (F8), the facies are fine-grained and well-sorted. Three of the eight facies constitute classic Bouma Sequence deposits; they are: F4, F5, and F6. F4, parallel to subparallel laminae is categorized as Bouma division Tb. Rippled or climbing-rippled sandstone, F5, is interpreted as Bouma division Tc and is the product of traction of grains along the sea bed during lower flow regime conditions. The final facies categorized within the Bouma Sequence is F6, a shale or mudstone, denoted by Te. Interpretations for the environments of deposition within each channel-fill sandstone on Spine 1, support the interpretation that these outcrops belong to a leveed-channel complex.

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